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NATURAL PHENOMENA HAZARDS PROJECT FOR DEPARTMENT OF ENERGY SITES

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ABSTRACT

Lawrence Livermore National Laboratory (LLNL) has developed seismic and wind hazard models for the Office of Nuclear Safety (ONS), Department of Energy (DOE). The work is part of a three-phase effort aimed at establishing uniform building design criteria for seismic and wind hazards at DOE sites throughout the United States. In Phase 1, LLNL gathered information on the sites and their critical facilities, including nuclear reactors, fuel-reprocessing plants, high-level waste storage and treatment facilities, and special nuclear material facilities. In Phase 2, development of seismic and wind hazard models, was initiated. These hazard models express the annual probability that the site will experience an earthquake or wind speed greater than some specified magnitude.

In the final phase, it is anticipated that the DOE will use the hazard models to establish uniform criteria for the design and evaluation of critical facilities.

INTRODUCTION

Lawrence Livermore National Laboratory (LLNL), has been working with the Office of Nuclear Safety (ONS), Department of Energy (DOE) to provide technical assistance in evaluating and developing building design criteria for facilities at DOE sites throughout the United States. The criteria in question are those relating to a structure's ability to withstand earthquakes and strong winds, from both tornadoes and other severe storms.

Building design criteria, developed by a uniform methodology, currently, does not exist for seismic, tornado, and high wind hazards at the various sites in the United States under the management of the DOE. In 1975, the Division of Operational Safety of the DOE asked LLNL for technical assistance in developing uniform building design criteria. A three-phase project was begun. The first phase, which was completed in 1978, involved information gathering, including:

- Selection of the DOE sites to be included in the project.
- Identification of critical facilities at each site and determination of the criteria for their selection.
- Review of the current seismic and high-wind design criteria in use at each site.

During this phase, critical facilities were defined, and information about such facilities at each site selected for the study was gathered and summarized.

Table 1 lists the DOE sites considered in this study. In general, the critical facilities at each site fell into one of the following categories:

- Nuclear reactors;
- Special nuclear materials facilities;
- Fuel-reprocessing facilities;
- High-level waste storage and treatment facilities;
- Hazardous chemicals storage facilities.

In the second phase, experts in seismic and extreme wind hazards were asked to develop models for each site. The methodology used and the final hazard models produced, are discussed in detail in references [1 and 2]. TERA Corporation, Berkeley, California, was selected to develop the seismic hazard models. McDonald, Mehta, and Minor, Consulting Engineers, Lubbock, Texas, and T.T. Fujita of the University of Chicago were both contracted to independently develop hazard modes for tornado and high winds. McDonald, Mehta, and Minor were selected to provide the engineering expertise in extreme wind hazard modeling while Fujita provided input from the meteorology point of view. LLNL has taken the input from both national experts and constructed a combined wind/tornado hazard model for DOE [1]. These models and the methodology used by the consultants in developing them are briefly discussed in this report.

SEISMIC HAZARD ANALYSIS

Seismic hazard analysis is the process of developing seismic input, peak ground accelerations and response spectra, for an area or region of interest. There are two distinctly different approaches to seismic hazard characterization--deterministic and probabilistic. In the deterministic

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TABLE 1. Project Sites, With DOE Field Offices.

DOE Field Office	Sites
Albuquerque, NM	Bendix Plant
	Los Alamos National Scientific Laboratory
	Mound Laboratory
	Pantex Plant
	Rocky Flats Plant
	Sandia National Laboratories, Albuquerque
	Sandia National Laboratories, Livermore
	Pinellas Plant, Florida
Chicago, IL	Argonne National Laboratory--East
	Argonne National Laboratory--West
	Brookhaven National Laboratory
	Princeton Plasma Physics Laboratory
Idaho	Idaho National Engineering Laboratory
Oak Ridge, TN	Feed Materials Production Center
	Oak Ridge National Laboratory, X-10, K-25, and Y-12
	Paducah Gaseous Diffusion Plant
	Portsmouth Gaseous Diffusion Plant
Nevada	Nevada Test Site
Richland, WA	Hanford Project Site
San Francisco, CA	Lawrence Berkeley Laboratory
	Lawrence Livermore National Laboratory
	Lawrence Livermore National Laboratory, Site 300
	Energy Technology and Engineering Center
	Stanford Linear Accelerator Center
Savannah, GA	Savannah River Plant

approach, the analyst must do the following:

- Decide that an earthquake of a given magnitude or intensity occurs at a certain location.
- Attenuate the ground motion from the earthquake source to the site.
- Determine the effects of that earthquake.

The problem with this approach is that it is difficult to define the margin of safety in the resulting design parameters. As a result, the analyst generally uses upper-bound estimates of ground motion, which are typically overly conservative.

In a probabilistic approach, on the other hand, the analyst quantifies the uncertainty in the number, size, and location of possible future earthquakes and can thus present a trade-off between more costly designs or retrofits and the economic or social impact of a failure.

Although the probabilistic approach requires significantly more effort than does the deterministic approach, we used it to develop seismic hazard characterizations in order to:

- Quantify the hazard in terms of return period.
- Rigorously incorporate the complete historical seismic record.
- Incorporate the judgement and experience of seismic experts.
- Account for incomplete knowledge about the locations of faults.
- Assess the hazard at the site in terms of spectral acceleration.

The method is particularly appropriate for eastern facilities where the seismicity is very diffuse and can not be correlated with surface faulting as it can be in the western United States. The location of the design earthquakes in the eastern United States is therefore particularly uncertain. The strength of the probabilistic approach is its ability to quantify these uncertainties. Its major weakness is the lack of plentiful statistical data from which to characterize the various input parameters in probabilistic terms. Nevertheless, the credibility of the probabilistic approach has been established through detailed technical review of its application to several important projects and areas. Applications include assessments of the seismic risk in Boston [3], the San Francisco Bay Area [4], the Puget Sound Area [5], the country of Nicaragua [6], the continental United States [7], the country of Costa Rica [8], the Nuclear Regulatory funded Seismic Evaluation of Commercial Plutonium Fabrication Plants [9], the Systematic Evaluation Program (SEP) [10], and the Seismic Safety Margins Research Program [11]. Results of these studies have been applied to, among other areas:

- Development of long-range earthquake engineering research goals.
- Planning decisions for urban development.
- Environmental hazards associated with the milling of uranium.
- Design considerations for radioactive waste repositories.
- Licensing decisions for plutonium fabrication facilities and commercial nuclear reactors.

This diversity of application demonstrates the inherent flexibility of the probabilistic approach.

Input

TERA used the probabilistic approach to characterize the seismic hazard for each site in this study. The input to a probabilistic hazard assessment comprises specification of local seismic sources, earthquake frequency relations and attenuation functions. Because hazard assessment calculations are very sensitive to the particular composition of the input, experts in local and regional seismology were consulted during the preparation of input for each facility.

Methodology Steps

The product of a probabilistic approach is a measure of the seismic hazard expressed in terms of return period, or reciprocal annual probability. The methodology used to determine seismic hazard at a site is usually divided into the following steps:

- Specify the geometry of local seismic regions. Based on the geology and historic seismicity of the region, sources are identified as line sources (faults) or area sources (Fig. 1a). The largest magnitude earthquake associated with each source is established.

- Describe past seismicity in terms of earthquake occurrence. The recurrence of earthquakes of various magnitudes is based primarily on historical seismicity. A straight line or a set of straight lines is fitted onto the data, using regression analysis to develop these relationships (Fig. 1b).

- Develop an earthquake recurrence model. The model assumes that the earthquake occurrence follows a Poisson distribution in time. This is a standard assumption.

- Derive or select a transfer function (attenuation relationship) to mathematically carry information from the epicenter to the site in terms of structurally relevant parameters (Fig. 1c). Most attenuation relationships are empirically derived, at times modified by theory, and express PGA as a function of earthquake magnitude and distances from the epicenter. Different attenuation relationships are used in the western and eastern United States because their ground motion characteristics vary significantly.

- Combine the potential activity of all sources for all earthquake magnitudes to determine the probability that a certain acceleration will not be exceeded within a given time period (Fig. 1d). This completes the seismic hazard model.

FUJITA'S TORNADO HAZARD METHODOLOGY

A methodology for assessing tornado hazards was also developed. Hazard is defined here as the annual probability of any point within a geographic region experiencing windspeeds in excess of some threshold

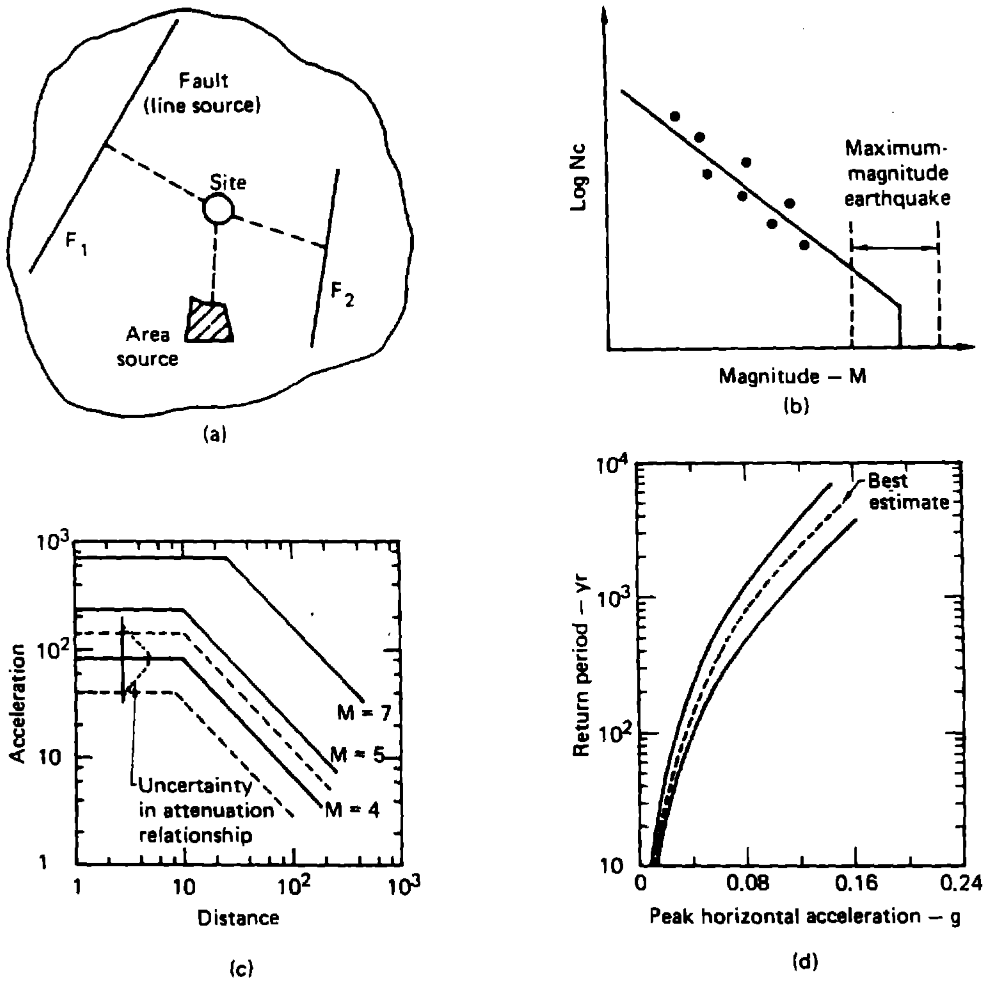

Figure 1 Methodology Steps for Seismic Hazard Characterization

value. As defined, this is a point probability that is independent of a structure's size and location within the geographic region.

The methodology uses available tornado records for the geographic region. The tornado hazard assessment method developed by Fujita and Abbey [12] accounts for gradation of damage along the length and width of the path in terms of mean damage path length, not mean damage area, and is expressed as:

$$P(F,V) = \frac{L_F \times \text{DAPPLE}(F,V)}{A \times Y} \quad \text{year}^{-1} \qquad (1)$$

where A is the statistical area; Y, the statistical year; L_F, the path length of F-scale tornadoes; and DAPPLE (F,V), the damage area per path length, which varies with F-scale and specified wind speed, V.

In 1975, Abbey and Fujita estimated DAPPLE values based on the Super Outbreak of tornadoes of 1974 at 50-mph intervals of maximum wind speeds for weak (F0 + F1), strong (F2 + F3), and violent (F4 + F5) tornadoes. Since then, Fujita computed DAPPLE values based on his Design-Basis Tornadoes, 1978 (DBT-78). Between September 1978 and February 1980, the mean values of DBT-78 DAPPLE and the initial Abbey/Fujita DAPPLE (AF-75) were used for hazard assessments.

Early in 1980, the mean DAPPLE was smoothed by using three empirical equations,

$$\text{DAPPLE} = 10^N \text{ in miles,}$$

where:

$N = -0.00078\ V^{1.496}$ for violent tornadoes,
$N = -0.00263\ V^{1.342}$ for strong tornadoes,
$N = -0.00930\ V^{1.293}$ for weak tornadoes,
V = the maximum wind speed in mph.

In the process of computing the various parameters contained in Eq. (1) the following steps are taken:

- A Statistical Area, based on a distance function for range weighting is determined. -- Fujita uses a cosine function to give less weight to tornadoes which occurred at increasingly greater distances from the site in question.

- A Statistical Years weighting function correction is made. -- This essentially corrects the data set to account for low reporting frequencies of tornadoes during early recording years.

- Gradation of damage along the path length is made. -- This correction accounts for variations in the windspeeds/damage across and along the tornado path length.

- Path Length Adjustments are made. -- These adjustments account for unreported tornadoes due to land characteristics and Land characteristics which preclude tornadoes.

In applying the DAPPLE method, L_F, A, and Y in Eq. (1) can be changed into their weighted values,

L_F into $\sum L_F''$

A into $A_S \sum G$

Y into $\bar{Y}$, the weighted

statistical year, where L_F is the range-corrected path length of F-scale tornadoes and is a function of the path length adjustments and the distance function. A_S is the area of the sub-box at the site, and G is a weighting function which is itself a function of the path length adjustments and the distance function. Using this notation, we can now express Eq. (1) as:

$$P(F,V) = \frac{\text{DAPPLE}(F,V) \; x \sum L_F''}{\bar{Y} \; x \; A_S \; x \sum G} \; \text{year}^{-1} \quad (2)$$

Equation (2) gives the probability of experiencing a windspeed of V associated with an F-scale tornado.

Since DAPPLE values are available for weak (F0 + F1), strong (F2 + F3) and violent (F4 + F5) tornadoes, statistical path lengths are computed not for each F scale tornado but for weak (w), strong (s), and violent (v) tornadoes. The probability of all tornadoes affecting the site can thus be computed as a sum:

$$P(V) = P(w,V) + P(s,V) + P(v,V) \quad (3)$$

MCDONALD'S STRAIGHT-WINDSPEED METHODOLOGY

In the United States, the work of Thom [13] has been used to evaluate the annual probability of straight winds exceeding some threshold value. Thom selected the Type II extreme value distribution (Fisher-Tippett Type II) to represent the annual extreme fastest-mile windspeeds. In all the cases compared by McDonald, the Type II distribution predicts higher windspeeds for a given mean recurrence interval than does the Type I distribution. At recurrence intervals of less than 100 yr, the differences are small. The windspeeds predicted by the Type I distribution for large recurrence intervals (500 to 10,000 yr.) appear to give more reasonable values of windspeed. The values are not significantly larger than upper-bound windspeeds expected in extratropical storms.

McDonald used Type II distribution in his first studies then switched to the Type I distribution for estimating straight-wind hazards because of the more reasonable windspeeds at large mean recurrence intervals. All sites included in this study have been evaluated using the Type I distribution. The details of the statistical methods used by McDonald, to evaluate straight-windspeed hazards, are beyond the scope of this report, but can be found in the hazard model summary report in reference [1].

In performing his calculations, McDonald corrects wind speeds to the 10-m anemometer height, and wherever available, utilized wind data records from the sites in question. A few of the sites had records listed in terms of fastest-one-minute wind speeds. The Fastest-one-minute wind speeds are converted to fastest-mile wind speeds to be consistent with the use of American National Standards Institute Standards ANSI A58.1.

The straight-winds obtained from the application of McDonald's methodology are expressed in terms of Fastest-mile wind speeds. A gust factor as defined in ANSI A58.1 should be included in the calculations for the design wind loads.

Figure 2 shows a typical combined extreme wind hazard model from McDonald and Fujita inputs.

FLOOD STUDIES

As a continuation of assessments of natural phenomena hazards at DOE sites, LLNL has initiated flood "screening" studies. The intent is to screen sites to identify those sites which do not realistically have flooding potential of concern and those that do. After this effort is completed, the next step would be to develop true flood hazard assessments for the high risk flood sites.

CONCLUSIONS

The hazard model for a given site is a tool that enables one to establish an acceptable level of hazard for a facility and thus deduce criteria for the design of new structures and the evaluation of existing ones. When the methodology is applied to several sites in different regions, design criteria at a consistent level of hazard can be established. A major advantage of this approach is that the hazard models are applicable to all types of facilities. The user evaluates the facility and its intended use and assesses the consequences of an accident. This allows a selection of a return period and thus definition of extreme wind and seismic design values.

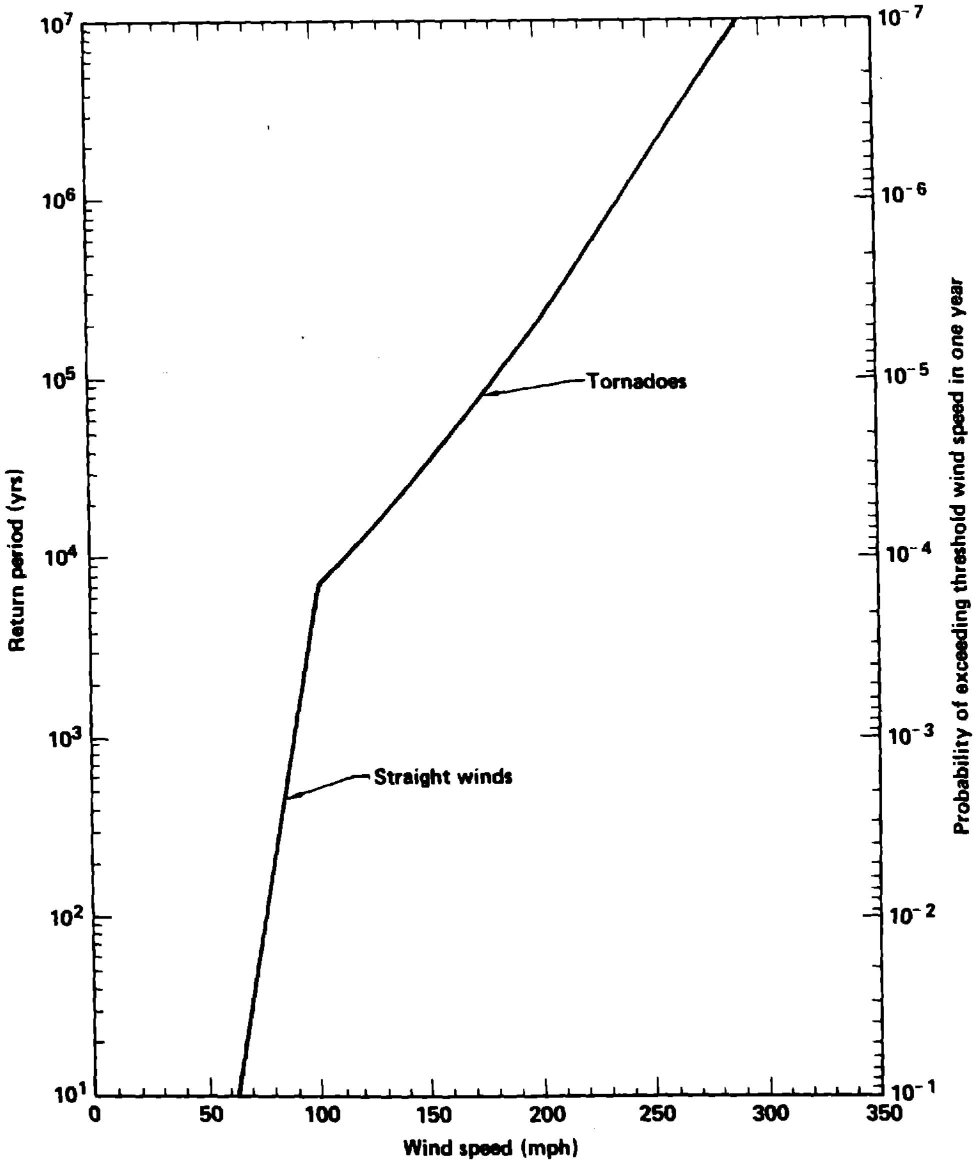

Figure 2 Typical Example of Final Wind/Tornado Hazard Model

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